RESEARCH DEPARTMENT

PICTURE PROCESSING BY QUANTIZATION OF THE TIME-DERIVATIVE

Report No. T-114

(1963/44)

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SUMMARY

A method of processing television pictures in order to facilitate channel-capacity reduction has been briefly investigated. The method combines some of the individual advantages of methods already investigated,[1] but the same elaborate instrumentation would be required for coding and transmission of the processed pictures.

1. INTRODUCTION

Most of the proposals that have been made for achieving transmission of television pictures in a reduced bandwidth involve conveying the picture information by means of a quantized signal - that is, a signal whose instantaneous value is confined to a number of discrete levels. This quantized signal is then translated, by means of a suitable code, into a signal capable of being transmitted in a bandwidth lower than that required by the original video signal. Unfortunately, the process of quantization always causes defects in the reproduced picture, the nature and severity of which depend on the content of the picture, the number of quantum levels employed, and the particular signal-parameter that is quantized. When quantization is applied directly to the video signal, spurious discontinuities of brightness occur in parts of the reproduced picture that should contain gradual changes of brightness; these discontinuities produce objectionable contouring effects when the number of quantum levels is restricted sufficiently for a worthwhile saving of channel capacity to be possible.

It has been widely realized that an advantage would be gained if, instead of quantizing the video signal itself, we were to quantize its rate of change with respect to time; this quantity will be referred to as the 'time derivative' or, more simply, the 'derivative' of the signal. It would then be possible to reproduce, by integration of the quantized derivative, a waveform that contained no spurious discontinuities of instantaneous value, although it would contain spurious discontinuities of slope; the displayed picture would not then be marred by the contour effects that result from direct quantization of the brightness. However, there is an obvious drawback to this approach, as is illustrated in Fig. 1. Fig. 1(a) represents a video signal, and Fig. 1(b) represents its time derivative. The result of quantizing the derivative is shown in Fig. 1(c), and Fig. 1(d) shows the reproduction of the original waveform that results from integration of the quantized derivative. It will be seen that the unavoidable errors introduced by quantization produce a cumulative error in the integrated waveform, which would result in unwanted streaks in the reproduced picture.

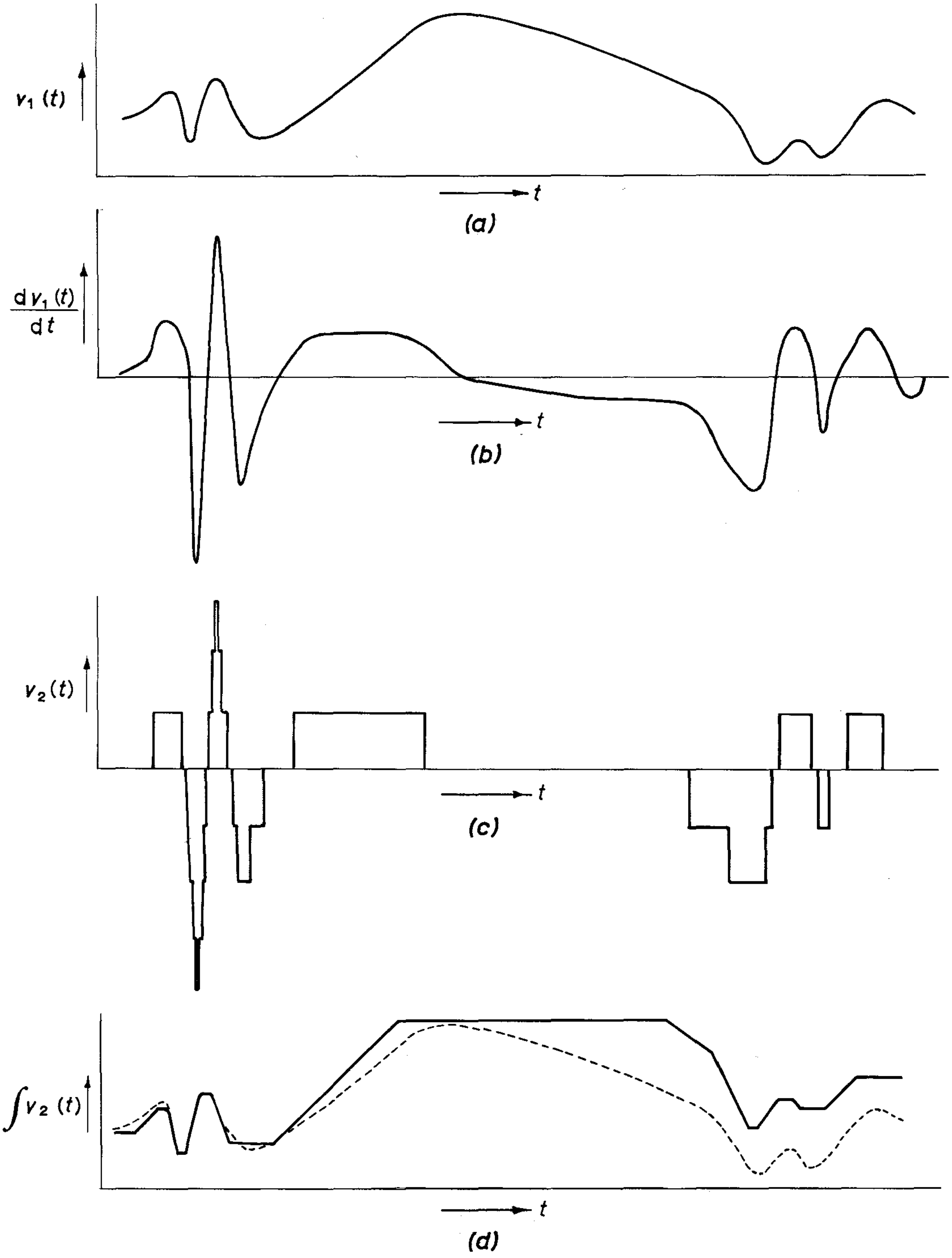

Fig. 1 - Waveforms in quantized derivative system

(a) Original video waveform; $V_1(t)$

(b) Time derivative of waveform (a); $dV_1(t)/dt$

(c) Quantized version of waveform (b); $V_2(t)$

(d) Integrated version, $\int V_2(t)\,dt$, of waveform (c), showing progressive departure from waveform (a) (dotted)

An earlier report[1] describes tests of three systems of bandwidth reduction; two of these systems relied on the transmission of a separate low-frequency signal having a bandwidth of 300 kc/s. It was realized that it would be possible to reduce the severity of the streaking by modifying the method of processing just described so as to include a suitable signal having this bandwidth. Very conveniently, the equipment that had been used for the assessment of the other systems was readily adaptable both to the basic method of processing already described and to the improved method employing a low-frequency correcting signal. It was, therefore, felt worthwhile to carry out a brief assessment of the improved system, which will henceforth be described as the 'quantized derivative' system.

2. DESCRIPTION OF THE SYSTEM

Fig. 2 is a simplified schematic diagram of a complete system incorporating the principles discussed. The waveform that results from integrating the quantized derivative waveform can be predicted at the transmitter by means of an auxiliary integrator, and an error signal derived by subtracting it from the original waveform. This error signal can then be restricted to a bandwidth of 300 kc/s by means of a low-pass filter and transmitted as the low-frequency signal. It should be noted, however, that the quantized waveform also contains components below 300 kc/s; the low-frequency signal must therefore be transposed, in the coder, to a higher range of frequencies, thereby increasing the total bandwidth requirement of the system.

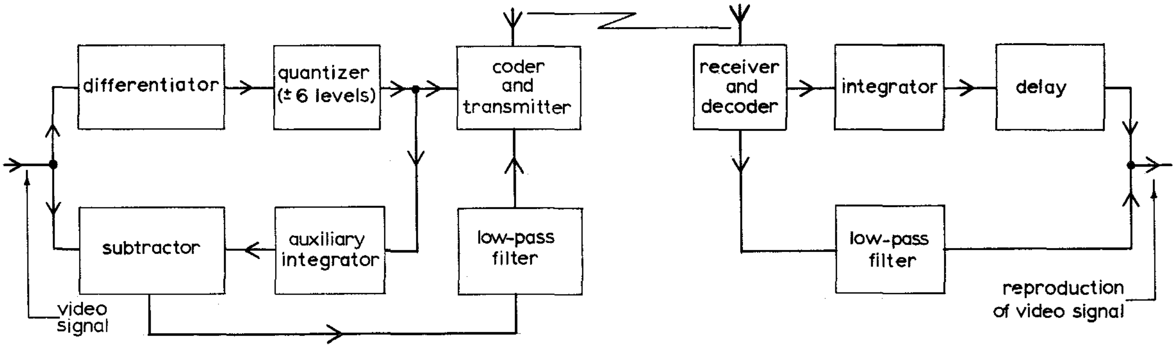

Fig. 2 - Schematic diagram of quantized derivative system

Fig. 3 shows the displays produced by the various waveforms in the system. The quantized derivative signal is shown in Fig. 3(a), and Fig. 3(b) shows the output of the integrator. The low-frequency correction signal is shown in Fig. 3(c), and Fig. 3(d) shows the result of adding this signal to the signal of Fig. 3(b). It will be seen that the objectionable streaks that mar the picture in Fig. 3(b) are completely eliminated by addition of the correction signal.

An alternative practical arrangement that is, nevertheless, equivalent to that of Fig. 2 is illustrated in Fig. 4. Here the low-frequency signal is obtained simply by passing the original video waveform through a low-pass filter at the transmitter; at the receiver the waveform produced by the integrator is passed through a high-pass filter. Finally, the correct low-frequency waveform is added in place of the erroneous components removed by the high-pass filter.

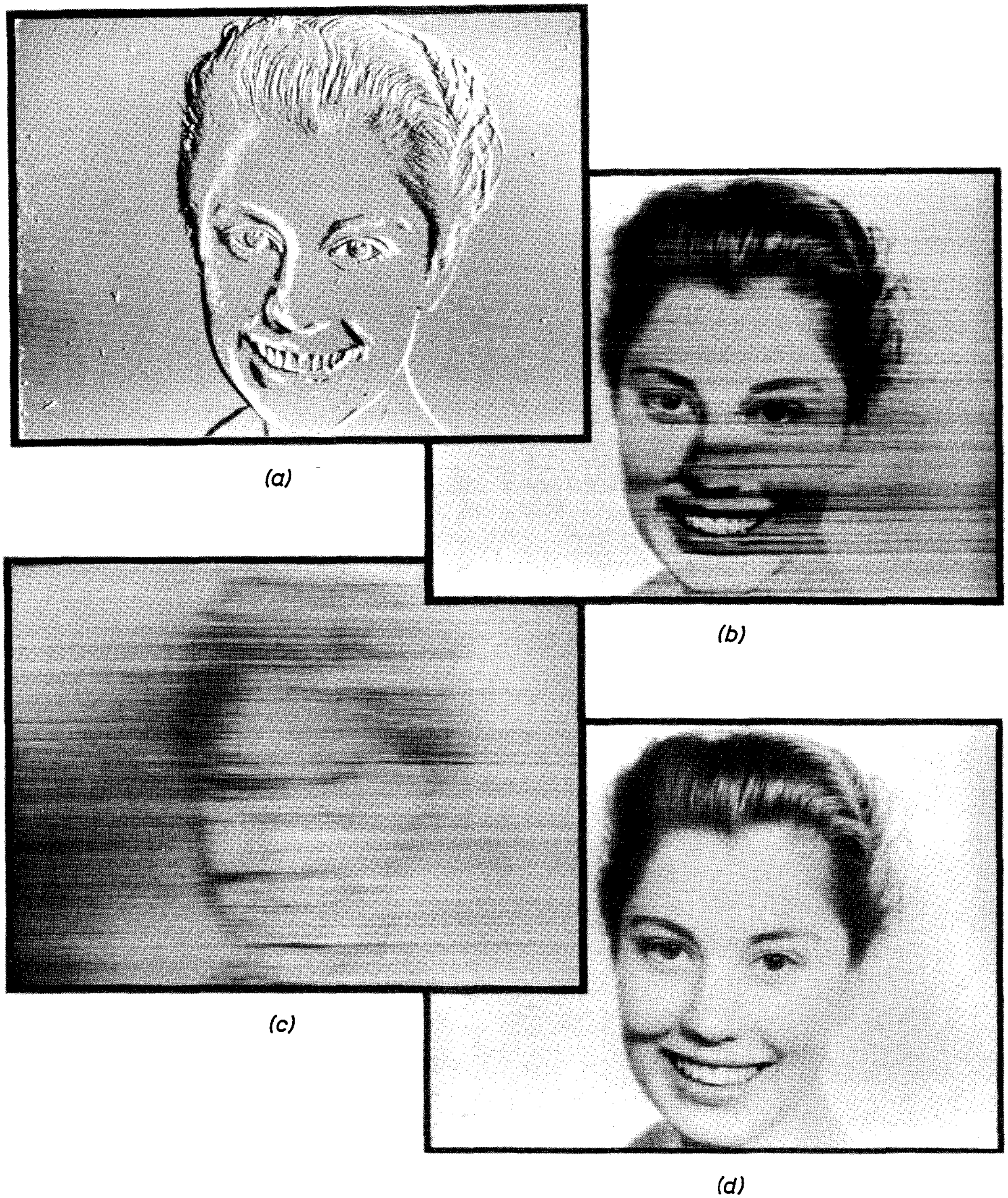

Fig. 3 - Displayed signals of the quantized derivative system

(a) Quantized derivative
(b) Integral of quantized derivative
(c) Low-frequency correction signal
(d) Sum of signals (b) and (c)

The quantized derivative system is in some ways similar to the 'synthetic highs' system described in reference 1; the synthetic-highs system, however, depends on the assumption that satisfactory reproduction is obtainable from a combination of low-frequency signals and sharp edges, whereas in the quantized derivative system all the information contained in the quantized derivative is transmitted. Pictures processed by the quantized derivative system can therefore include satisfactory reproduction of brightness changes that are too rapid to be conveyed entirely by the low-frequency signal, but are not so abrupt as to constitute sharp edges. A shortcoming of the synthetic-highs system is that such changes can be reproduced either as sharp edges only, or, incompletely, by their low-frequency components alone.

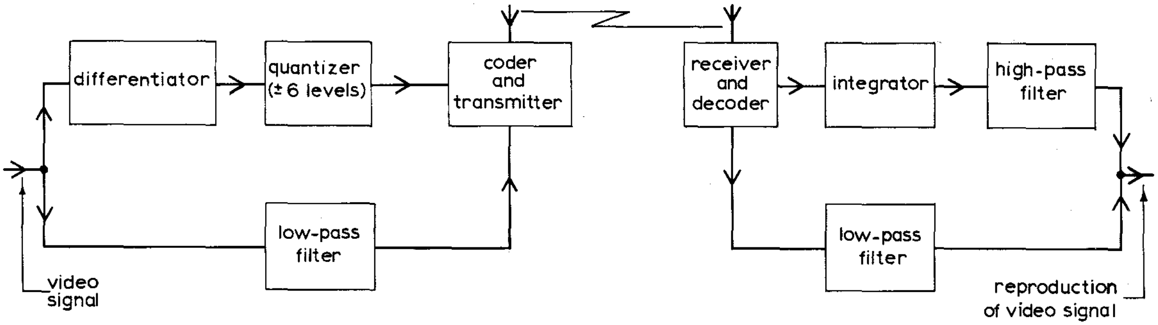

Fig. 4 - Schematic diagram of alternative arrangement to that of Fig. 2

The quantized derivative system was tested using six positive and six negative quantum levels. It was found that, in these conditions, very few gradual brightness changes, relative to the number of sharp edges, were reproduced by means of the quantized derivative signal. By slightly attenuating the highest video frequencies in the original signal and increasing the level fed to the quantizer, the reproduced picture was made to contain a greater number of gradual brightness changes and a smaller number of low-contrast edges; this was found to improve the picture quality appreciably.

3. CHANNEL CAPACITY REQUIREMENT

The practical advantage offered by a system that enables signals to be transmitted in a reduced bandwidth cannot be assessed merely in terms of the degree of bandwidth reduction achieved; the signal-to-noise ratio that must be maintained in the transmission channel of reduced bandwidth is also highly relevant. In fact it is a perfectly straight-forward matter to reduce the bandwidth required for transmission of a given signal by any desired factor, provided that the signal-to-noise ratio, in decibels, of the transmission channel is increased by the same factor. A useful figure of merit for a bandwidth compression system is the inverse of the product of the bandwidth, in megacycles, and the signal-to-noise ratio, in decibels, required at the receiver. When this product is evaluated for a communication channel it is proportional to a quantity defined by Shannon[2] as the 'channel capacity' of that channel.

If then, a signal-to-noise ratio of 30 dB is regarded as just acceptable for a 405-line television signal having a video bandwidth of 3 Mc/s, the product $1/(3 \times 30) = 1/90$ affords a basis of comparison with the corresponding product for systems claimed to be more efficient.

The reader is referred to the earlier report[1] for a description of coding methods by which bandwidth compression might be achieved for quantized signals, and of the experimental procedures for assessing the required bandwidth by direct measurement of the quantized signal, without the necessity of actually coding it. It is necessary here to state one result only: the signal-to-noise ratio required at the receiver is about 45 dB, this being the threshold value for completely error-free recovery of the quantized picture from the coded signal. As the signal-to-noise ratio falls below this value the picture quality deteriorates rapidly, serious positional errors occurring as well as brightness errors of a particularly objectionable type.

An additional bandwidth of 300 kc/s must, of course, be provided for transmission of the low-frequency signal. The visibility of a given r.m.s. noise level is higher for coarse noise than for fine and it is, therefore, probable that a signal-to-noise ratio of 30 dB, assumed acceptable for conventionally transmitted television, would barely be adequate for the low-frequency signal.

4. TESTS OF PERFORMANCE

Thirteen still pictures were processed by the quantized derivative system. The pictures came from a 3¼ inch × 3¼ inch (82·6 mm × 82·6 mm) flying-spot scanner, using the same slides that were used in the previous tests. For each picture the required bandwidth was assessed by counting the number of transitions in the quantized waveform, and the picture quality was assessed by the writer using a six-point scale, ranging from 'excellent' to 'very poor'.

It was found that it would be necessary to provide an overall bandwidth of 1·1 Mc/s in order to transmit ten of the thirteen pictures, or of 1·2 Mc/s in order to transmit twelve of them. The thirteenth picture, which was of a suburban garden with houses in the background, would have required 1·6 Mc/s, although the processed picture was only rated as 'fairly good'. The picture quality was rated as 'excellent' for two of the pictures, 'good' for seven, 'fairly good' for three and 'rather poor' for one.

When attempts were made to reduce the bandwidth requirements by reducing the amplitude of the input to the quantizer, the number of pulses in the quantized derivative signal representing gradual brightness changes decreased rapidly, and the performance of the system approximated to that of the synthetic-highs system.

When motion pictures were used, the performance of the quantized derivative system was found to compare with that of the other systems in much the same way as it did for still pictures.

5. DISCUSSION OF RESULTS

The picture quality obtainable by the use of the quantized derivative system, with a total bandwidth requirement of about 1·2 Mc/s, is noticeably better than that obtained, with a total bandwidth requirement of 1·0 Mc/s, by means of any of the three systems previously tested. None of these three systems has been assessed with the operating conditions adjusted to require a total bandwidth greater than 1 Mc/s; however, the nature of these systems makes it unlikely that, even if the bandwidth were increased to 1·2 Mc/s, the picture quality would equal that obtainable within this bandwidth by means of the quantized derivative system.

It must be remembered that in this report no consideration has been given to the complexity of the equipment that would be necessary for a complete realization of this system. It would, for example, be necessary for the equipment to include two storage systems, each containing at least 20,000 cells, in order to allow picture detail to be redistributed over the entire picture area. Moreover, because of the stringent signal-to-noise ratio requirements of the processed signals, the saving in channel capacity that would result from reducing the bandwidth to 1·2 Mc/s is only about 1·7 : 1.

It was established in the earlier investigation that none of the systems could produce a picture that was subjectively preferable to that resulting from simple bandwidth reduction by means of a 1 Mc/s low-pass filter, followed by a 'crispening' circuit. It is the writer's opinion that the quantized derivative system would similarly fail to produce better results than could be obtained from a 1·2 Mc/s filter and a crispener.

6. CONCLUSIONS

The quantized-derivative system is capable of producing better pictures than were obtained with any of the systems previously tested, but requires a total bandwidth of at least 1·2 Mc/s if its distinctive advantages are to be realized; the required signal-to-noise ratio is about 45 dB.

On balance, the superiority of the system to those already tested is insufficient to affect in any way the conclusion reached in the earlier report, namely, 'that where television is intended for broadcast entertainment, bandwidth compression methods of the types investigated are unlikely to prove worthwhile'.

7. REFERENCES

1. 'Tests of Three Systems of Bandwidth Compression of Television Signals', Research Department Report No. T-080, Serial No. 1962/1.
2. Shannon, C.E., 'A Mathematical Theory of Communication', B.S.T.J., July and October 1948, Vol. 27, Nos. 3 and 4.

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